CoBOP Coral Reefs: Optical Closure of a Coral Reef Submarine Light Field

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LONG-TERM GOALS

The primary goal for this project is to obtain optical closure of the submarine light field overlying coral reef environments by measuring the basic optical properties of the water column and benthic surfaces. These measurements can also be used to develop remote sensing algorithms for the determination of biomass, diversity and primary production of benthic corals, seagrasses and macroalgal communities.

SCIENTIFIC OBJECTIVE

Our objectives are to investigate the time scales of variability and effects of tidal and wind driven flow on water column inherent and apparent optical properties . It is our opinion that there will be times when efforts to remotely sense benthic communities will be thwarted due to the dominance of water column optical properties under conditions of high flow in shallow waters. We are attempting to combine fluorescence signatures with algorithms which will measure the kinetics of photosynthesis, our objective is to have a system which assesses the contribution of algal color groups to the total primary production over large regions of shallow water. The key is to establish the relationship of fluorescence yield to photosynthetic rate. We will determine the reflectance spectral signatures of corals, seagrasses and unconsolidated sediments in meter scale patches and as individual organisms. Specific emphasis will be placed on the changes in spectral reflectance and fluorescence as a function of depth.

APPROACH

An Aanderaa Model DCM12 upward looking ADCP/tide gauge/wave analyzer with near-bottom optical instruments attached to the frame is used to assess the contribution of tidal and wind induced flow to increased optical variability in the water column. The ADCP unit operates at 606.7 Hz and is designed for deployment in 3-50m of water. Three to five depth cells above the null (bottom) cell are monitored for current speed and direction. State of tide (water level) and significant wave height are measured using a quartz pressure cell and determined as $H^{1/3}$. Data are logged internally as three minute averages. The optical package consists of a Sea-Bird Electronics Seacat 19 CTD, WETLabs miniature WETStar chlorophyll fluorometer and WETLabs CStar single channel transmissometer (25cm path, 488nm). Sample water is pumped through the system to ensure sample turnover and reduce fowling, the optical windows are cleaned daily by divers. Water column optical properties are monitored three times daily by profiling a WETLabs AC-9 and CTD package and by Niskin bottle samples for spectral particulate and dissolved absorption and chlorophyll concentration.

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When dark adapted plant material is irradiated by short wavelength light, the amount of fluorecence emission (fluorescence yield) rapidly increases to a maximum value, then slowly declines, the 'Kautsky effect'. The total time required for the emission to reach baseline is called the fluorescence lifetime, which, for photosynthetic pigments *in vivo*, is on the order of minutes. The experimental procedure is to submerge specimens in sea-water within an enclosed chamber, irradiate with actinic blue light and measure the fluorescence decay of pigments with a photodetector. Photosynthetic oxygen evolution is measured simultaneously by an electrode penetrating the chamber wall. Both fluorescence and oxygen production are recorded as a function of time providing the relationship between fluorescence and photosynthesis from corals, seagrasses and macroalgae.

Budgetary estimates of photon flux in the water column are anchored by measurements of incoming and water leaving spectral irradiance and specific biogenic and non-biogenic substances which attenuate light. Chlorophyll and accessory photosynthetic pigments such as carotenoids and phycobilin pigments are found in the water column and in different benthic organisms. We have extended the Chlorophyll Accessory Pigment (CAP) ratio classification technique (Yentsch and Phinney, 1985; Topinka, et al., 1990) using fluorescence spectral signatures to encompass benthic organisms including corals, seagrasses and macroalgae. Reflectance can be used to classify benthic substrates and organisms through a combination of spectral signatures and the overall quantity of light reflected (ie. 'albedo'). Spectral reflectance measurements are performed in the laboratory and *in situ* using an Analytical Spectral Devices Field Spec spectrometer with 512 channels between 340 and 1080nm. In the lab, diver collected specimens are uniformly illuminated and spectral reflectance is measured under white light conditions referenced to a standard plaque. In situ measurements are obtained by a diver placing a 10m fiber optic collector next to a specimen and measuring the reflectance under natural light referenced to a standard plaque measurement (Spectralon 99% standard) obtained under the same light conditions.

WORK COMPLETED

Our efforts this year have been divided between collection and analysis of water column optical properties and shallow water reflectance data obtained during the 1998 CoBOP field experiments at Lee Stocking Island in the Bahamas. Our results on inherent optical properties and tidal currents were measured at a site located between North and South Perry reefs by David Phinney. A total of thirty-one vertical AC-9/CTD profiles were obtained, 14 at the ADCP site, 8 at the N. Perry site in support of FILLS activities and two series of offshore transect stations to determine local hydrographic conditions. Discrete salinity, chlorophyll and particulate absorption measurments were also collected from Niskin bottles. The ADCP/bottom optics package was deployed for two 4-day sampling intervals with 95% data recovery. Charles Yentsch measured more than 900 hyperspectral reflectance spectra of benthic substrates, flora and fauna in the shallow waters surrounding Lee Stocking Island, Norman's Pond Cay and at Rainbow Gardens. Measurements of the 'Kautsky effect' were not performed, laboratory experiments will continue this year in Key West with implementation at Lee Stocking Island in 1999.

RESULTS

Water column optical variability was less than in the Dry Tortugas at only +/-30% for spectral beam c observed over a series of tidal cycles. The optical signals were also much less correlated with tide, as were temperature and salinity. For our site away from Adderly Cut, near-bottom effects were not pronounced. The largest factor affecting optical variability appeared to be the advection of deep, cold

(>50m and <25.5ºC) clear water from beyond the narrow shelf edge up into the shallows. Warm, saline water from Adderly Cut was displaced by this cold water which was significantly clearer. Horizontal gradients were nearly absent to 2.5 km offshore water depth was in excess of 700m.

We have compared the spectral reflectance of a benthic macroalgae to the transmission of optically pure water (Figure 1). The reflectance spectrum of wetted Sargassum was measured in air. The spectral transmission of water is a compilation from two laboratory studies (Smith and Baker, 1981; Palmer and Williams, 1974). The visible region was defined as 400-750nm, the near infrared is 750-1050nm. In most plants we measured, the reflective infrared shows little or no absorption. This reflection is believed to be due to large molecules and cellular structure (early workers referred to this as infrared fluorescence). In contrast, the reflectance in the visible region is determined by the absorption of photosynthetic pigments. Thus, in a general sense, spectral reflection from algae is the inverse of light transmission, i.e. high in the near infrared and low in the visible region.

We emphasize that the above simulation is for water with the highest known clarity. In terms of being able to detect these wavelengths from surface measurements, this is the best possible case. Critical to

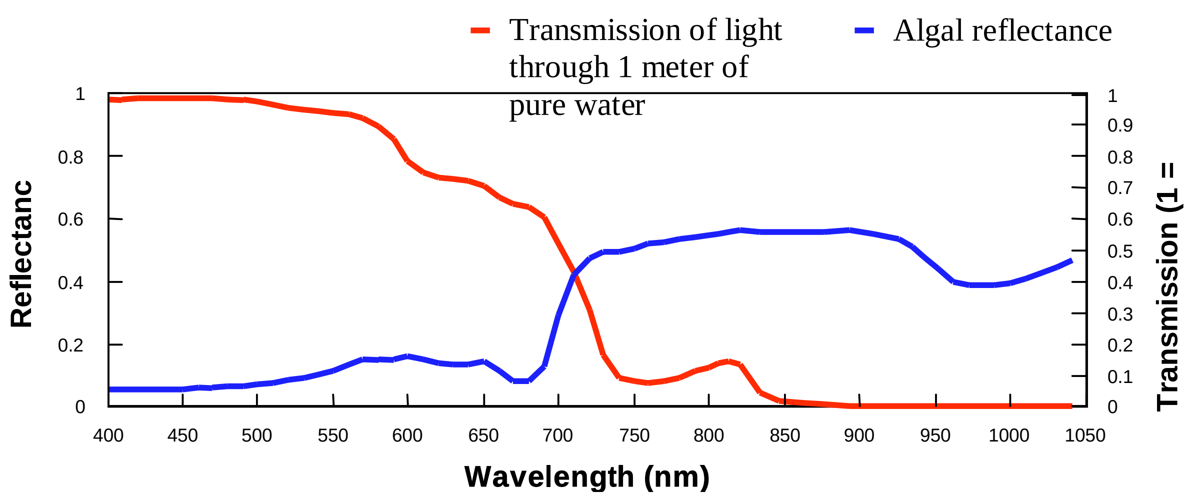

Figure 1. Spectral transmission of pure water and the reflectance spectrum of Sargassum platycarpum. Visible data (400-800nm) from Smith and Baker (1981); near IR data from Palmer and Williams (1974).

the generalization of this situation is the relationship between visible reflectance and that in the near infrared. We have compared this relationship in species of both micro- and macroalgae and found it reasonably constant with reflectance in the near infrared at 3-5 times higher than that in the visible region. Of course there are algae with higher albedos than Sargassum. We are interested in this species since it is known to grow on coral reefs and as such, may be an indicator of the decline of the reef.

IMPACT/APPLICATIONS

We believe that our measurements will permit the development of algorithms which will relate spectral reflectance measured by passive remote sensors to shallow water benthic communities in coral reef environments. The structure of these communities can be described by their diversity and potential to support primary production which affect the overall ability of the substrate to absorb light. We are also evaluating the effect of physical forcing due to tides on water column optical variability in shallow waters. Our ability to optically discern benthic communities is highly dependent on the transmission of light through overlying waters. The use of near infrared wavelengths holds promise for mapping distributions of plants or bathymetry in very shallow waters. More importantly, near-IR wavelengths are used to determine the atmospheric corrections for ocean color sensors. Ignoring the contibution of these wavelengths to the upwelling light field in shallow waters will significantly affect the accuracy of passive remote sensing products.

TRANSITIONS

We are not aware of any transitions to the fleet or persons in other countries. The North Perry Reef spectral beam c data have been distributed to the Naval Surface Warfare Center at Panama City, FL (Mike Strand) and Raytheon Corp in Tewksbury, MA (Bryan Coles) for incorporation with the FILLS sensor dataset.

RELATED PROJECTS

We continue to collaborate with Ken Carder (USF) and Ron Zaneveld (OSU) on measure-ments of the absorption characteristics of water column particulates and inherent optical properties. AC-9 profiles at N. Perry Reef were performed in support of Laser Line Scanner operations with Mike Strand (NSWC, Panama City) and Bryan Coles (Raytheon). Measurements of the spectral reflectance signatures of individual coral and algal species in the field will be compared to similar analyses by Charles Mazel (MIT) in order to develop a catalog which can be used to describe optically similar groups of organisms. A remote sensing group has developed with Curt Davis (NRL) as chair, our optical measurements will be coordinated to the overflights in 1999.

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